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U.S. ARMY TACOM

LASER SURFACE HARDENED PATTERNS FOR INCREASED BALLISTIC PROTECTION

Contract No. DAAE07-82-M-9053

April 1983

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Laser transformation hardening of selected patterns on RHA armor plate, represents a potential method of increasing ballistic capabilities of this material. This program applied 16 rows of 1/2 x 1 in. surface hardened patterns to 18 armor plates in two heat-treated conditions and two patterns. Tests indicated that the hardened patterns achieved a hardness level of 55-59 HRC. The plates were returned to TACOM for ballistic evaluation.

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1.0. INTRODUCTION

Past efforts at increasing the ballistic protection afforded by passive monolithic armor plates have led to increased obliquity, greater thickness, additional armor plates with or without spacing, packaged nonmetallic additions, and the use of chains, bars, and ribs. Each had drawbacks either in increased space, wieght, cost, or fabrication problems. The development of high-energy lasers capable of surface hardening metallic surfaces may provide a more acceptable means to upgrade ballistic protection level for a given plate thickness or allow the reduction of armor plate thickness requirements.

The acceptance of CO_2 lasers in industry to enhance the mechanical properties of hardenable steels and cast irons is an established fact. In surface hardening, the laser generates a very intense energy flux at the workpiece surface. The CO_2 laser projects a beam of energy in the form of infrared energy (10.6 micron) which is easily controlled, requires no vacuum, and generates no combustion product. The resulting temperature profiles in the workpiece can be made steep enough to produce a transformation-hardened "case" without the need for an external quench.

Laser heat treatment metallurgy relies on extreme nonequilibrium conditions with respect to heating and cooling cycles. It therefore presents a potential for unique metallurgical properties. The quench severity which is a characteristic of the laser heat treatment process results in the nucleation (formation) of lower temperature transformation products from austenite phase, and it is independent of classical hardenability concepts where carbon and alloy content dictate the severity of quench. In other words, unique martensitic/bainitic microstructures, which cannot be developed by the conventional heat treatment technology, are potentially capable of being produced by laser techniques. Such unique structures can exhibit very good impact properties. The alloy composition and the metallurgical conditions produced by the laser (finer grain size and martensitic/bainitic phase) could be expected to lower the transition temperature and result in a substantial increase in toughness of the steel. The comparatively high Mn/C ratio in the armor plate, coupled with the martensitic structure developed by the laser hardening method, would also be expected to enhance the impact properties to a great extent.

2.0. OBJECTIVE

This program was concerned with implementation of increased hardness patterns on the surface of armor plates. Specifically, the objective was to produce patterns of hard areas in relatively soft (tough) plates. For example, areas of 600 Brinell Hardness Number (BHN) would be produced in RHA plates with hardness ranging from 341 to 381 BHN (see MIL-A-12560 Table IV).

3.0. CONCLUSIONS

In this short program, laser surface hardening of armor plates was found to be feasible. Hardness profiles confirm the presence of 100% martensite in the hardened case to an appreciable depth without grain coarsening in the heat-affected zone.

Utilizing laser parameters to produce a lower-power/slow scan rate hardened case and a high-power/fast scan rate hardened case, 18 out of 24 armor test plates were hardened with either one of two hardness patterns, straight and staggered. These plates were returned to the Government's technical representative.

4.0. DISCUSSION

4.1. Material

In order to achieve the hardness objective, the Government provided twenty-four 18 in. by 18 in. by 3/8 in. thick, steel armor plates. The plates were reported to have been cut from two larger plates (identified as "A" and "B") and were marked:

- Single Notch: Plate A
- Double Notch: Plate B

The contractor maintained this identification system for each plate. The side of the plate used to produce hardness patterns was designated as "front" of the plate. Plates were also given a serial number which related to the procedure and pattern applied.

Upon receipt, IITRI examined the armor plates to determine the necessary processing and laser beam characteristics required to produce controllable increased hardness zones at adjustable depths. A thickness check revealed that the plates had been surface ground on both faces such that their thickness was 0.3 in. This presented no problem since full quench is achieved as long as the workpiece thickness is approximately 5 times greater than the case depth (typically 0.06 in. or less for these tests).

However, a hardness test of the as-received plate revealed that it was already near full hardness at 515 BHN. As such, the plate would not produce the differential hardness pattern desired in these tests.

The contractor was directed to reduce the hardness of eighteen plates to the 344-388 BHN range. A chemical analysis, Table 4-1, was conducted to permit the proper heat treatment to be specified.

TABLE 4-1. Composition of Test Plates

Plate	Analysis, weight percent								
	C	Mn	Si	P	S	Ni	Cr	Mo	Fe
A	0.28	1.35	0.13	0.007	0.013	0.04	0.02	0.25	Bal.
B	0.29	1.36	0.13	0.008	0.015	0.04	0.02	0.24	Bal.

The 18 plates were tempered to the 344-388 BHN range by heating to 825°F (±10°F) for 1 hour and air cooling while bound together in a pack to minmize loss of carbon from the "front" surfaces of the plates. The pack technique resulted in only a minimal blue scale, suggesting little or no carbon loss. Plates remained substantially flat. A post-treatment check revealed a 336-353 BHN based on conversions from 36-38 Rockwell "C" scale reading.

The remaining 6 plates were left at the original 515 BHN hardness to provide a second base plate condition upon which to place a laser-hardened pattern.

4.2. Establishing the Procedure

Because the armor plates were at two hardness levels--hardened to 515 BHN (as-received), and tempered to 336-353 BHN--preliminary trials were aimed at demonstrating two regimes of laser heat treating for each of the heat-treated conditions. The first regime deals with obtaining maximum surface hardness, but at the expense of case depth. This is accomplished through the use of high beam power densities (fluxes) and fast scan rates. The second regime involves deep case formation and slightly lower surface hardness by employing low power densities and slow scan rates.

Microhardness traverses and microstructures of these trials are seen in Figures 4-1 through 4-10. These results confirm the presence of 100% martensite in both conditions to an appreciable depth without any grain coarsening in the heat-affected zone. It is interesting to note that the laser heat treating cycle is capable of developing fully hard martensitic structure even in a 0.28 wt% carbon steel with a section thickness of only 0.30 in.

4.3. Test Plate Hardening

Based on the results of the armor plate response to the laser exposure,

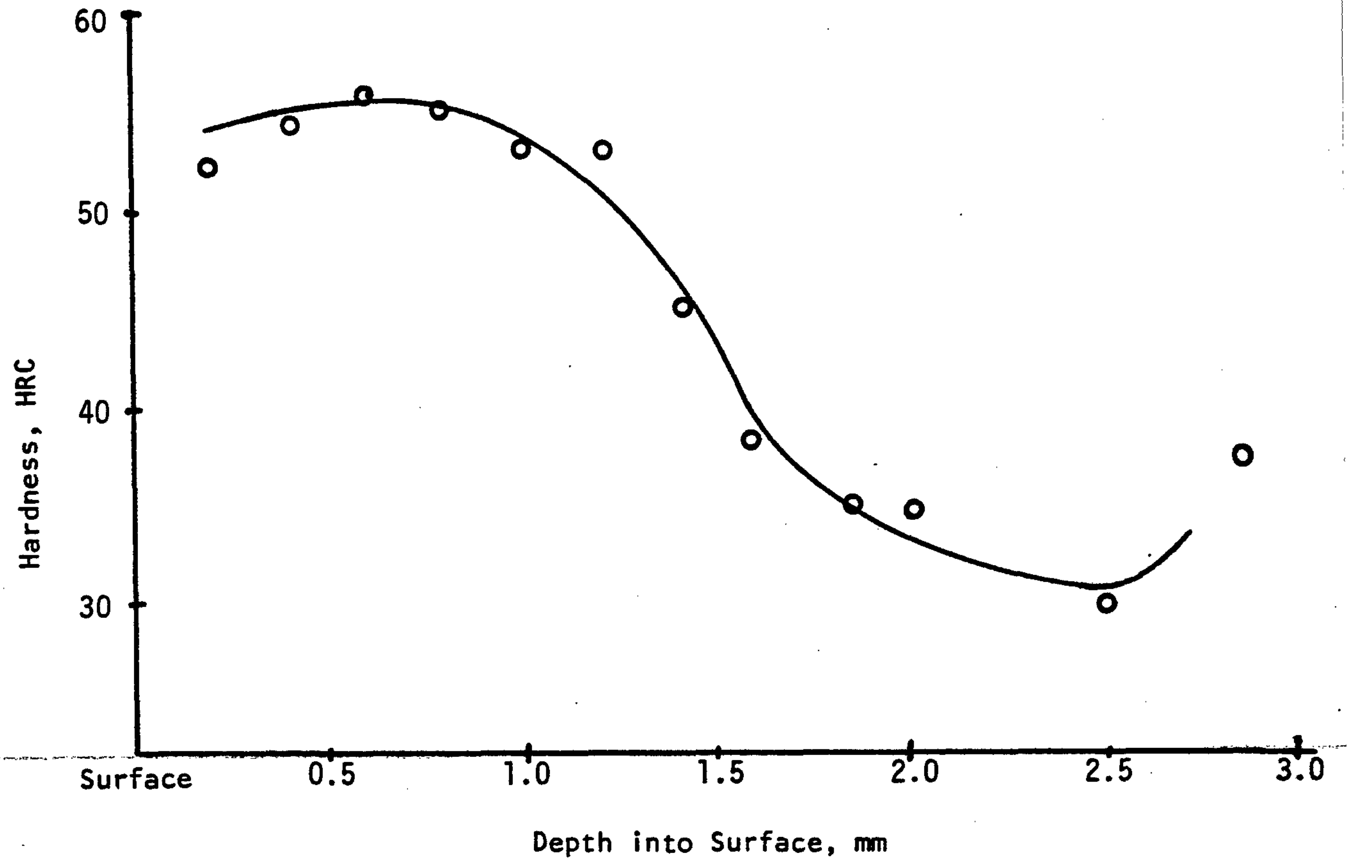


Figure 4-1. Microhardness Traverse of Armor Plate Fully Hardened (Sample 1a-2) Exposed at 40 ipm and 4 kW

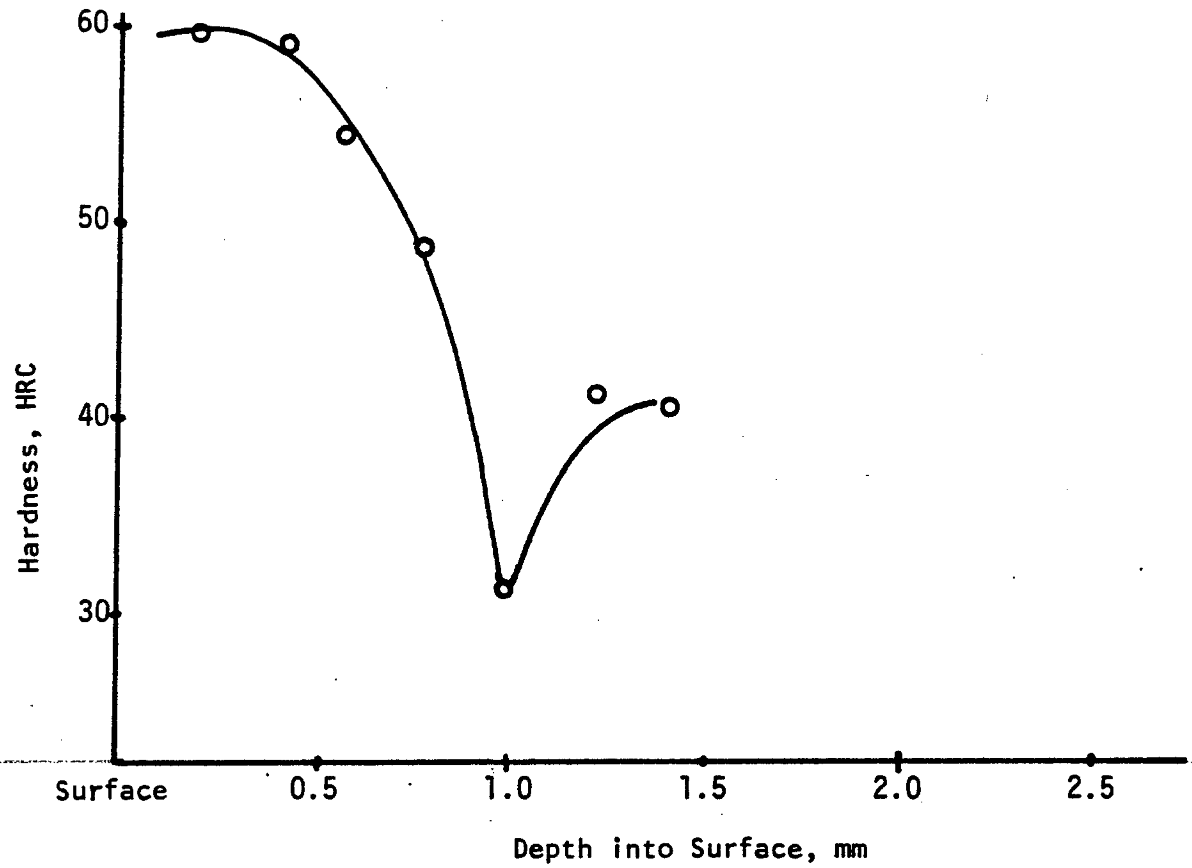


Figure 4-2. Microhardness Traverse of Armor Plate Fully Hardened (Sample la-2) Exposed at 60 ipm and 4 kW

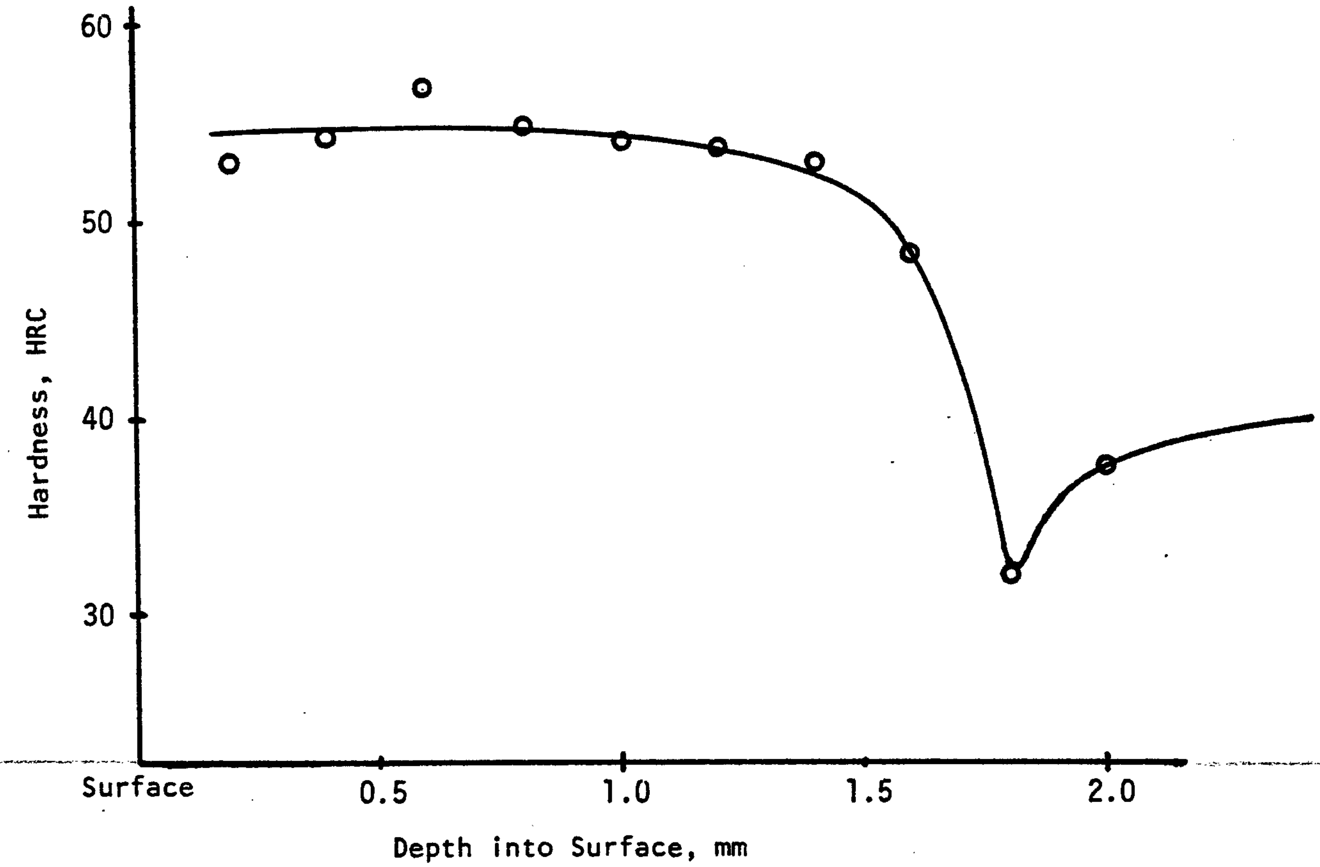


Figure 4-3. Microhardness Traverse of Armor Plate Fully Hardened (Sample 1a) Exposed at 32 ipm and 4 kW

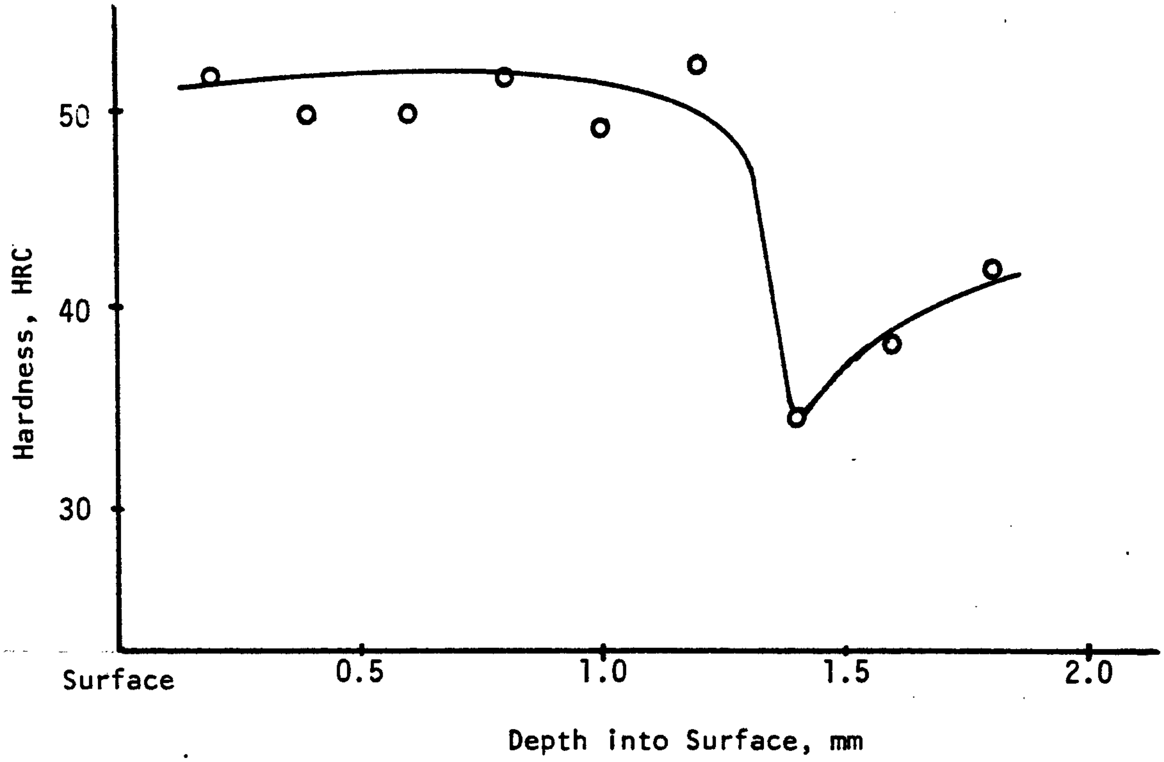


Figure 4-4. Microhardness Traverse of Armor Plate Fully Hardened (Sample 1a) Exposed at 48 ipm and 4 kW

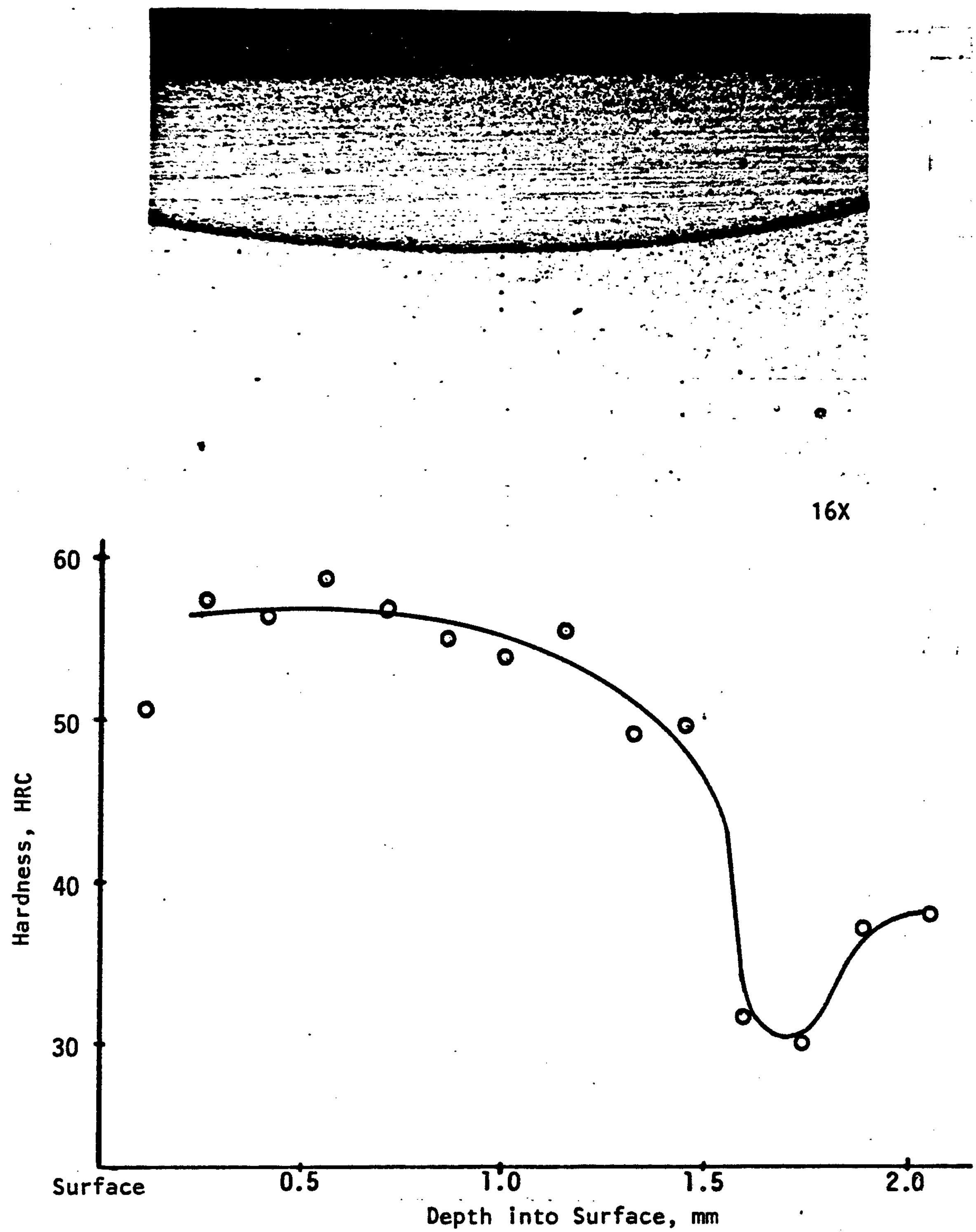


Figure 4-5. Microhardness Traverse and Microstructure of Armor Plate Exposed at 16 ipm and 2.0 kW (Sample B3-4-1)

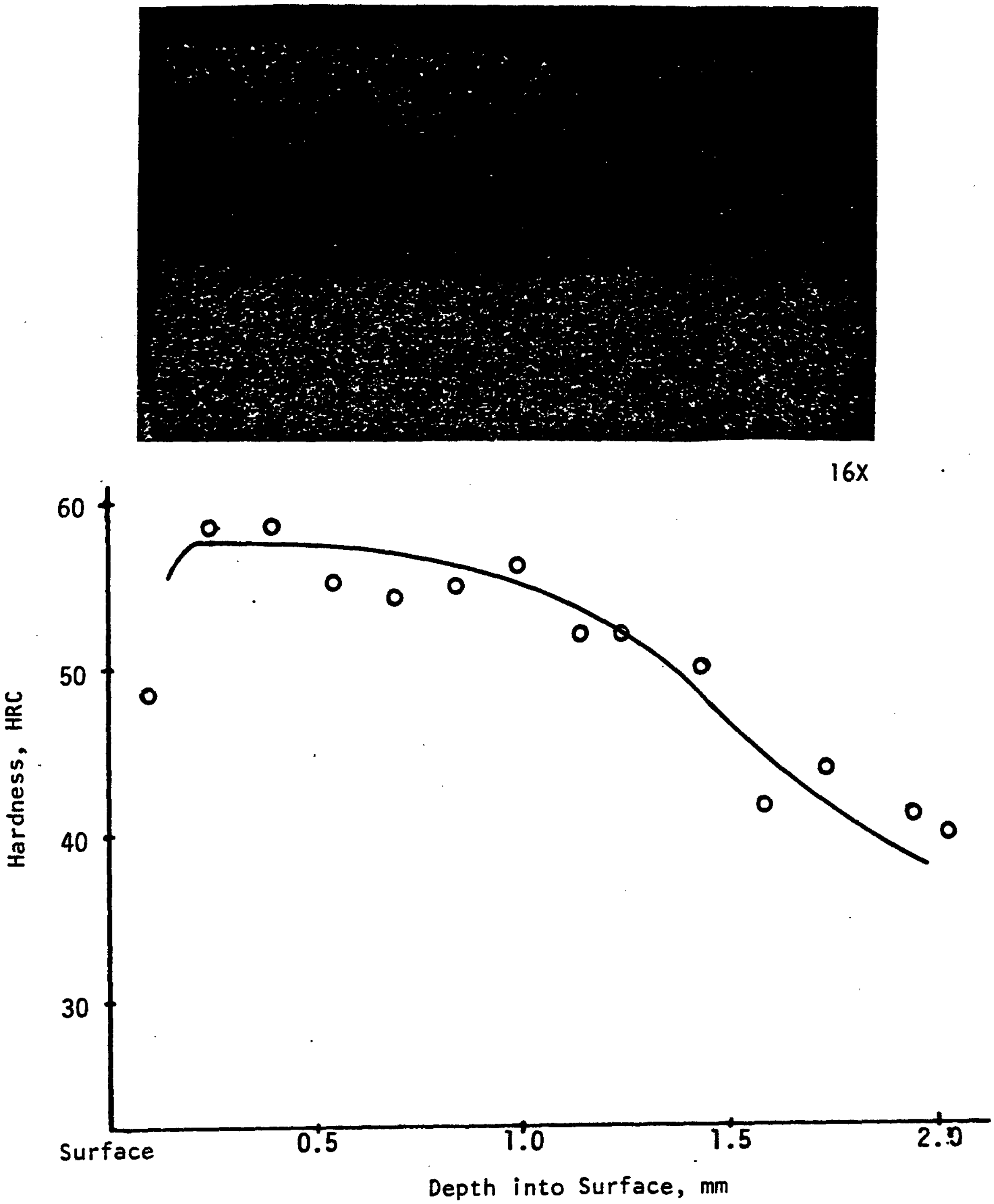
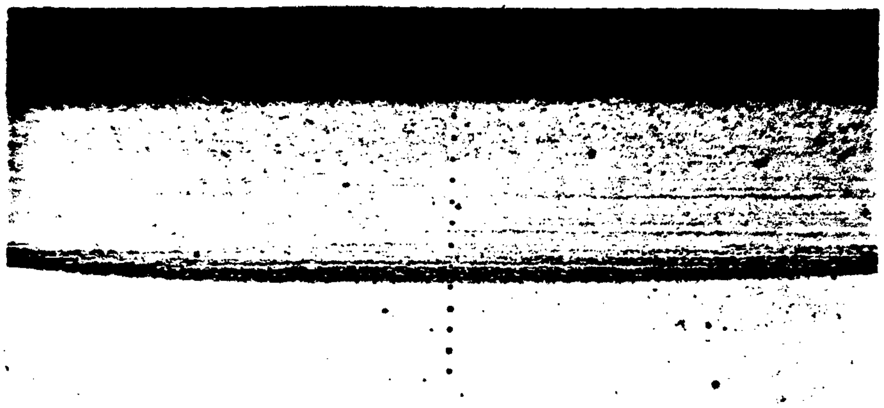


Figure 4-6. Microhardness Traverse and Microstructure of Armor Plate Exposed at 16 ipm and 2.5 kW (Sample B3-4-2)



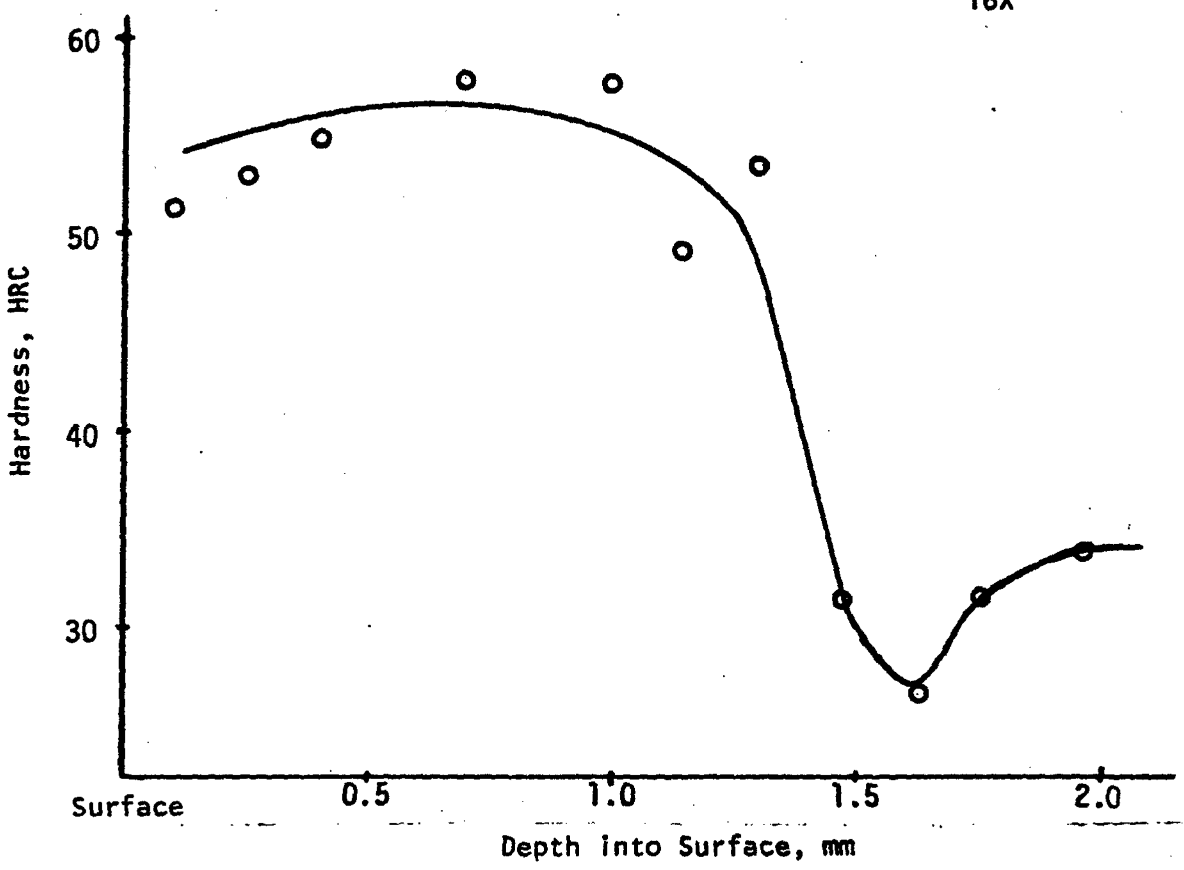
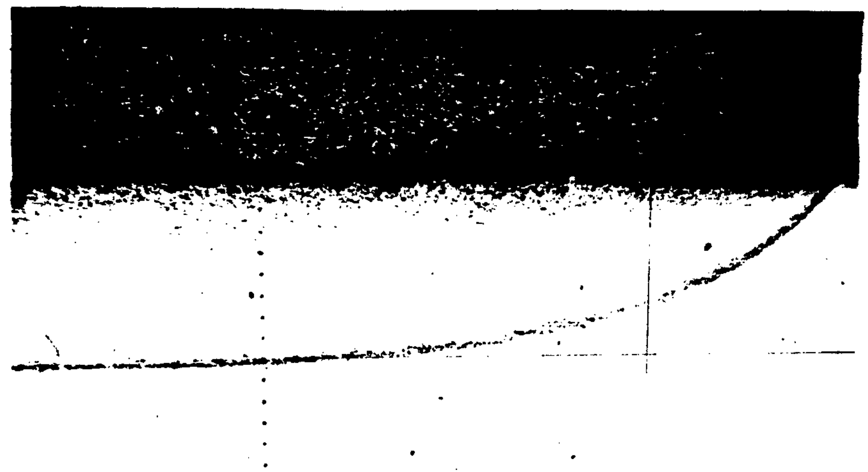


Figure 4-7. Microhardness Traverse and Microstructure of Armor Plate Exposed at 40 ipm and 4.0 kW (Sample A3-4-1)



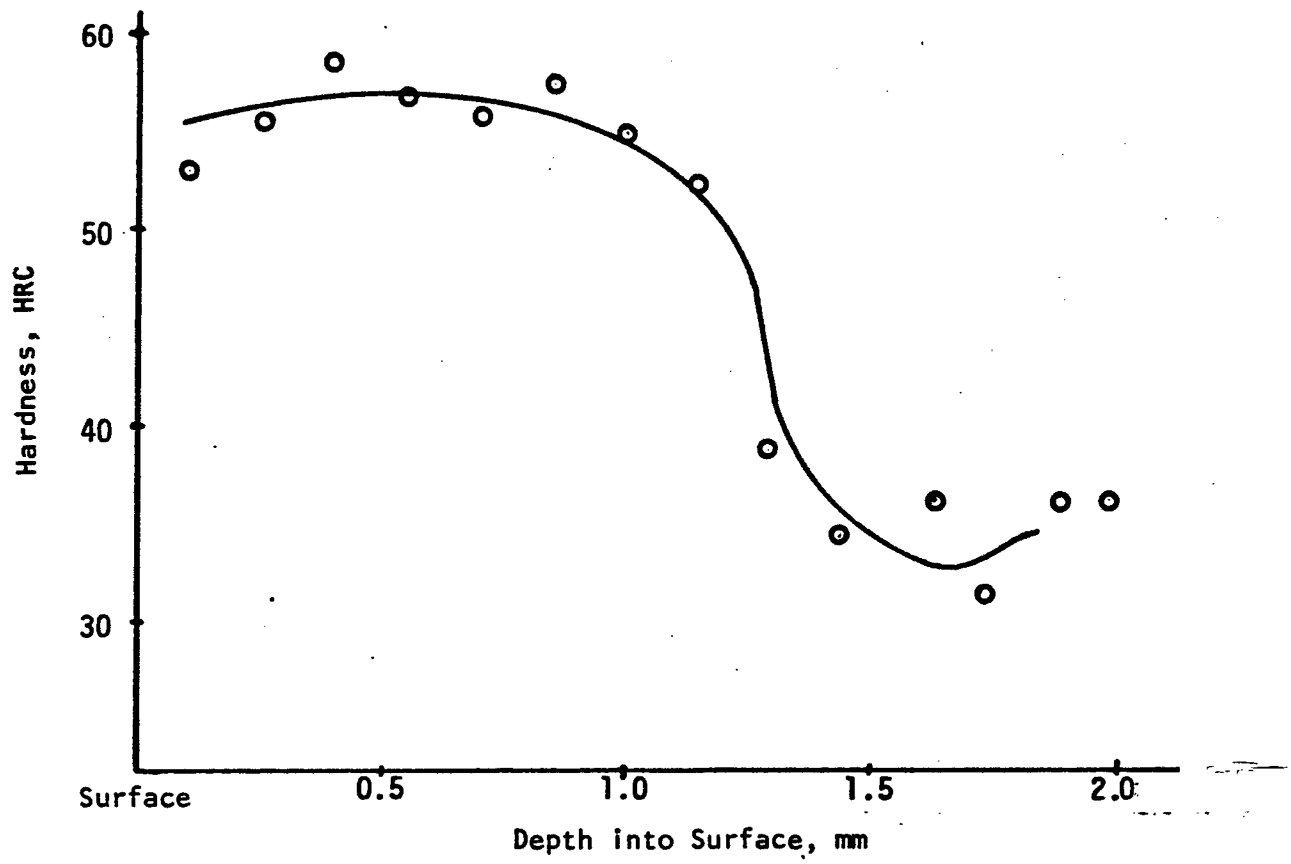
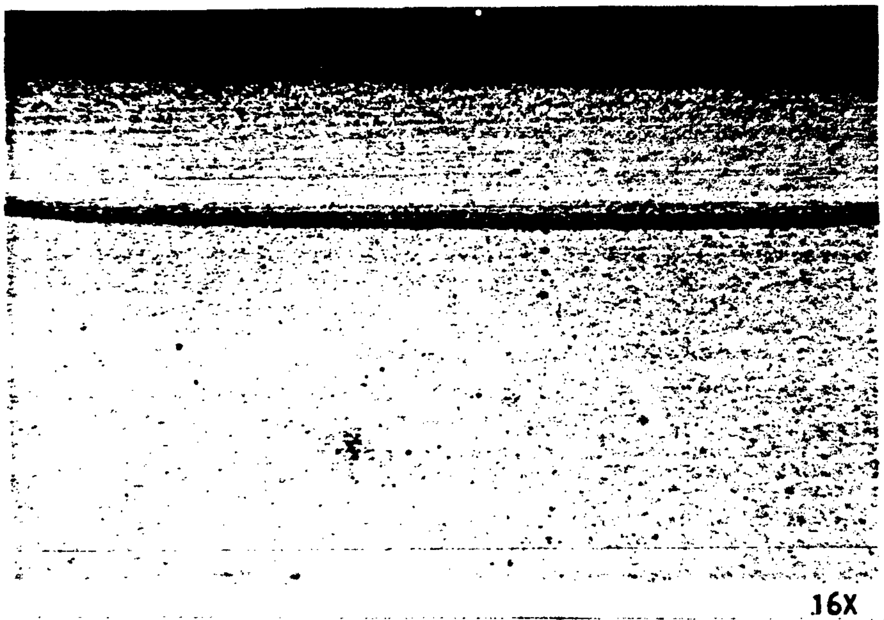


Figure 4-8. Microhardness Traverse and Microstructure of Armor Plate Exposed at 48 ipm and 4.0 kW (Sample A3-4-2)



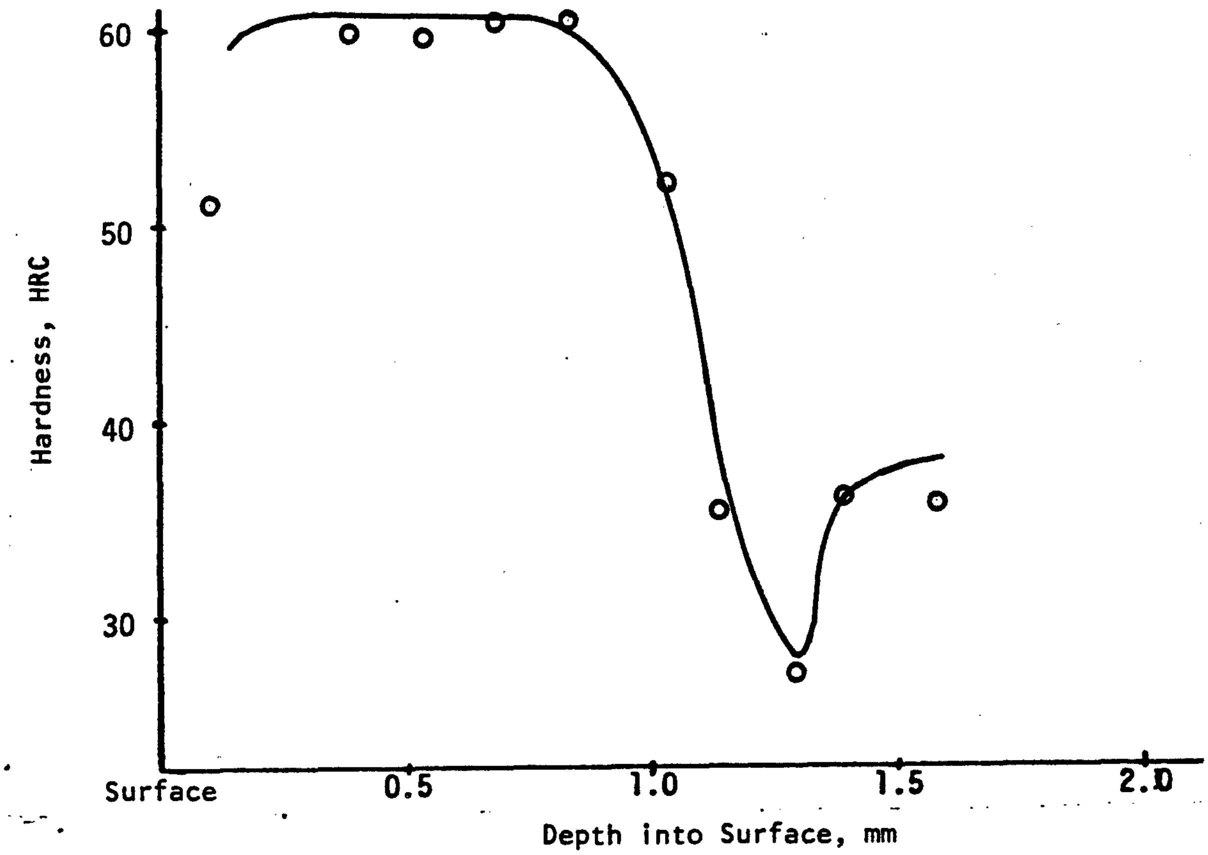


Figure 4-9. Microhardness Traverse and Microstructure of Armor Plate Exposed at 60 ipm and 4.0 kW (Sample A3-5-1)

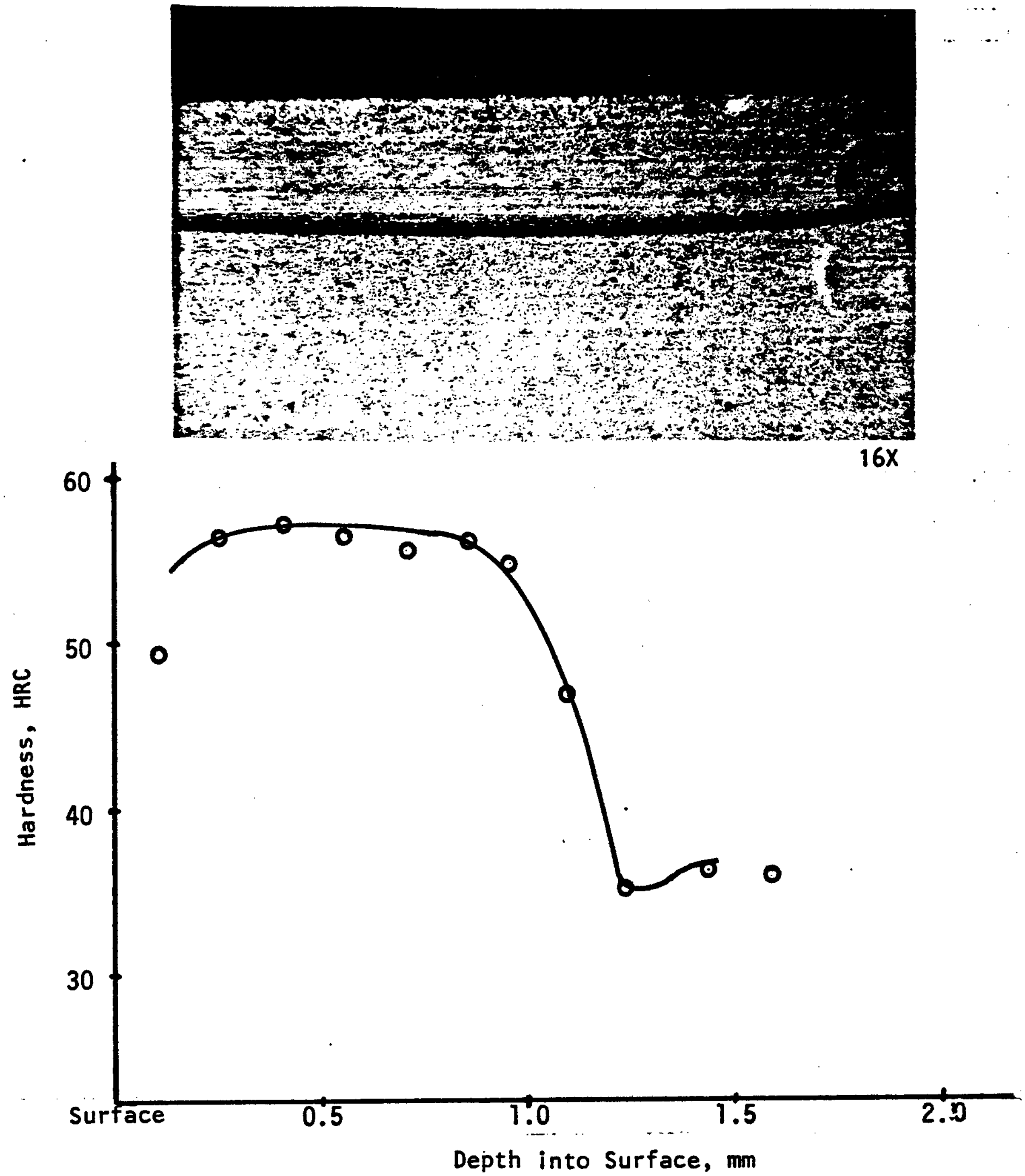


Figure 4-10. Microhardness Traverse and Microstructure of Armor Plate Exposed at 60 ipm and 5.0 kW (Sample A3-5-2)

two sets of laser parameters (power/scan rate) were chosen to produce a low/slow and a high/fast hardened case for both the fully hardened and tempered plates. These laser parameters were then applied onto 18 of the 24 test plates having the two hardness conditions. The two patterns applied, straight and staggered, are shown in Figures 4-11 and 4-12. A breakdown for treatment of the initial 24 plates is shown in Figure 4-13. This figure details the laser parameters used on the 18 laser-hardened plates; 6 tempered plates were held out for control specimens. A total of 24 plates were shipped back to the Government for further evaluation, 18 laser-hardened plates plus 6 control plates.

The 18 laser heat treated plates were then measured for distortion. It was found that during the laser heat treatment of the plates, the plates tended to distort, bowing up on the corners. The distortion was measured in 3 directions (Figure 4-14), and is recorded in Table 4-2. The distortion may have resulted from the reduced thickness of the plate and the large surface area being laser treated. The broad area, thin plate apparently did not have enough modulus to resist the compressive residual stresses generated in the case by the laser. If the plate were thicker, this distortion might not occur. It was also found that if both sides of the plate were hardened by the laser, as with plate A1, distortion could be totally eliminated.

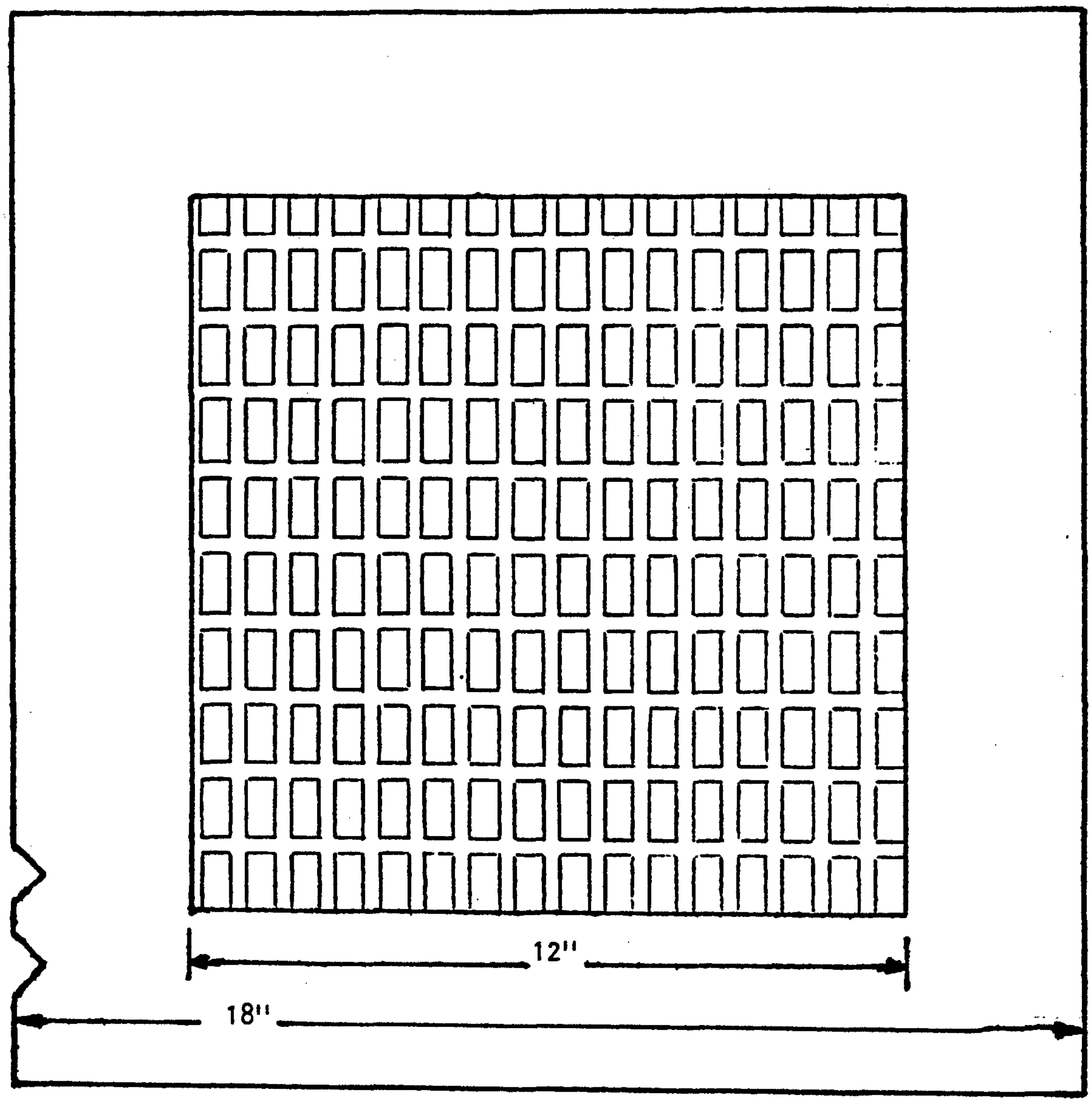


Figure 4-11. Straight Pattern of Laser Hardened Areas, 1/2 x 1 in. with 1/4 in. Spacing

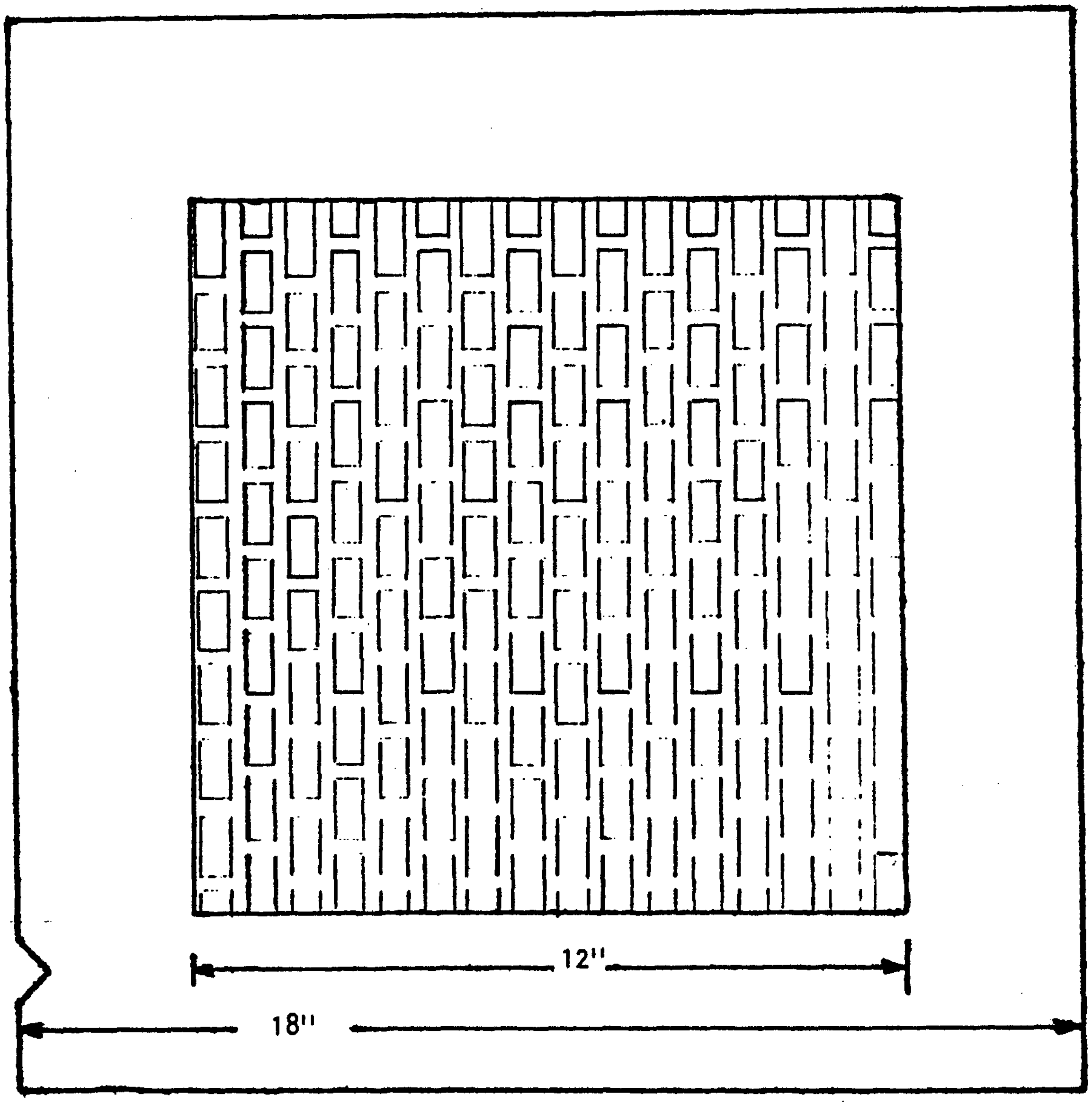


Figure 4-12. Staggered Pattern of Laser Hardened Areas, 1/2 x 1 in. with 1/4 in. Spacing

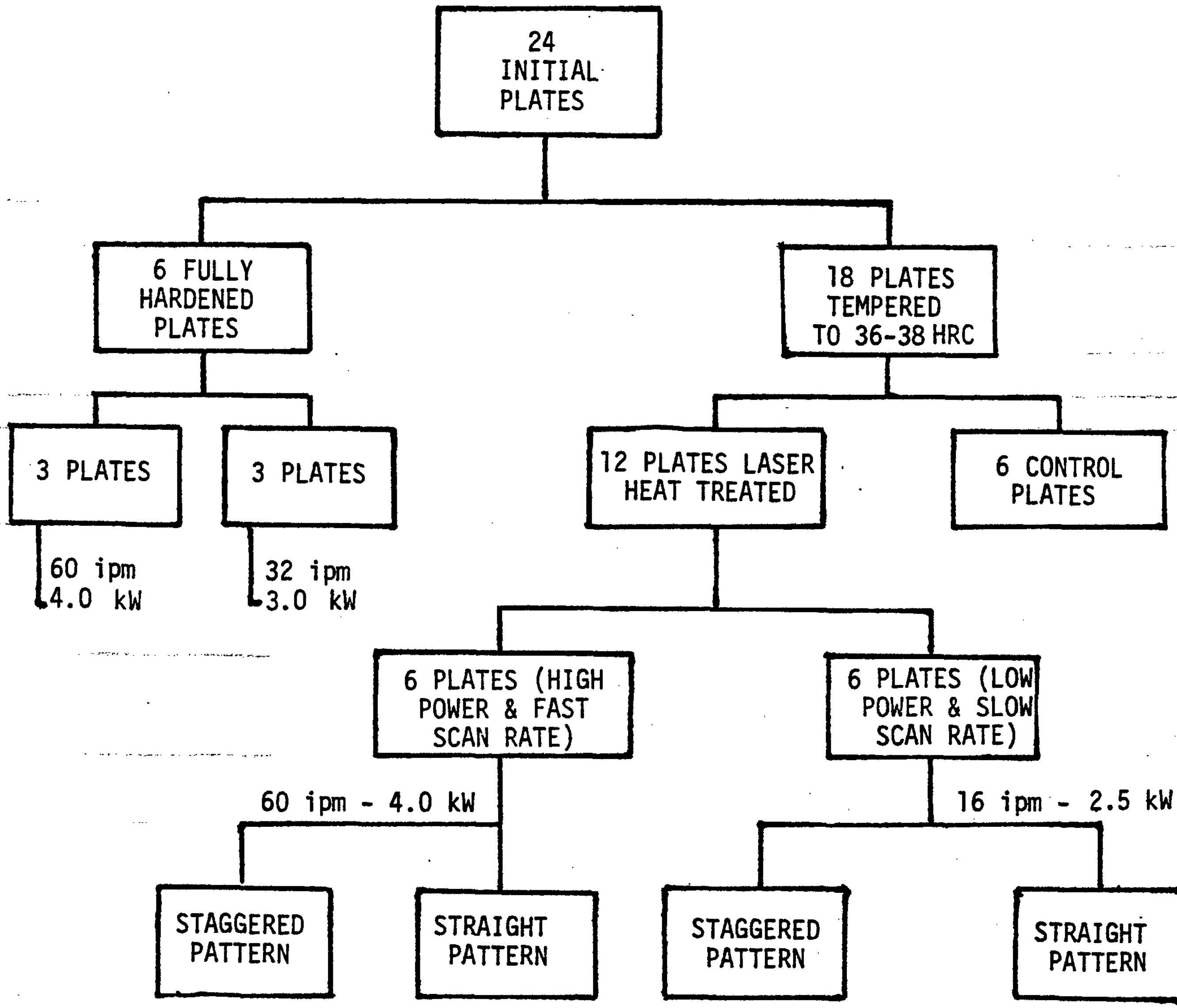


Figure 4-13. Breakdown for Treatment of Armor Plates

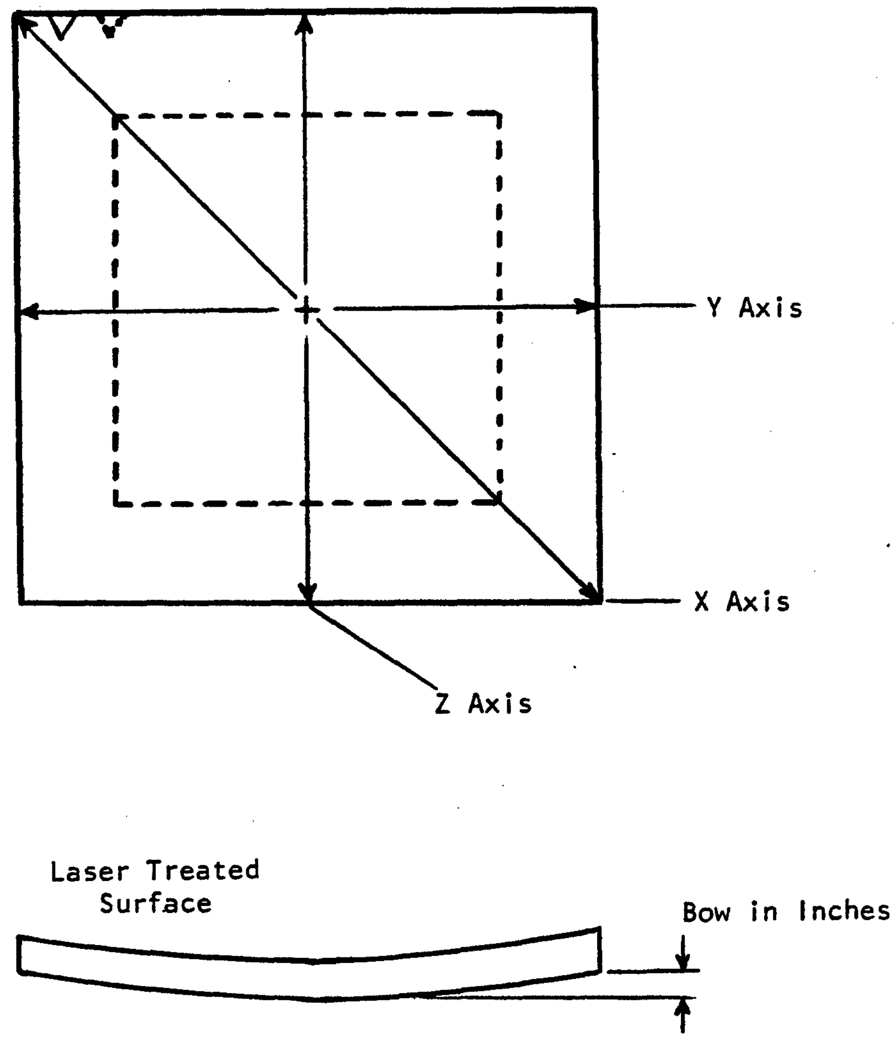


Figure 4-14. Measurement of Plate Distortion in 3 Directions

TABLE 4-2. Measurement of Plate Distortion

Plate No.	Base BHN	Laser Heat Treat Speed, ipm	Laser Heat Treat Power, kW	Distortion, in. X Axis	Distortion, in. Y Axis	Distortion, in. Z Axis
A1	515	32	3.0	0.345	--	--
A1[a]	--	32	3.0	0.045	0.015	0.012
A2	370	Control Plate		--	--	--
A3	370	Control Plate		--	--	--
A4	370	60	4.0	0.142	0.110	0.060[b]
A5	370	60	4.0	0.138	0.115	0.062[b]
A6	370	60	4.0	0.125	0.110	0.050[b]
A7	370	Control Plate		--	--	--
A8	370	16	2.5	0.210	0.160	0.110[b]
A9	370	16	2.5	0.210	0.160	0.100[b]
A10	370	16	2.5	0.230	0.160	0.105[b]
A11	515	32	3.0	0.355	0.395	0.210
A12	515	32	3.0	0.360	0.245	0.200[b]
B1	515	60	4.0	0.300	0.240	0.112
B2	370	Control Plate		--	--	--
B3	370	Control Plate		--	--	--
B4	370	60	4.0	0.138	0.105	0.060
B5	370	60	4.0	0.126	0.110	0.050
B6	370	60	4.0	0.140	0.125	0.040
B7	370	Control Plate		--	--	--
B8	370	16	2.5	0.218	0.170	0.110
B9	370	16	2.5	0.218	0.160	0.115
B10	370	16	2.5	0.210	0.146	0.100
B11	515	60	4.0	0.252	0.190	0.162
B12	515	60	4.0	0.296	0.215	0.185

[a]Laser heat treated back side of plate A1

[b]Staggered

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